## Exercise 9E - Vertical Motion Under Gravity

**1** A cliff diver jumps from a point 28 m above the surface of the water. Modelling the diver as a particle moving freely under gravity with initial velocity 0, find:

**a** the time taken for the diver to hit the water **b** the speed of the diver when he hits the water.

**2** A particle is projected vertically upwards with speed 20 m s$^{-1}$ from a point on the ground. Find the time of flight of the particle.

**3** A ball is thrown vertically downward from the top of a tower with speed 18 m s$^{-1}$. It reaches the ground in 1.6 s. Find the height of the tower.

**4** A pebble is catapulted vertically upwards with speed 24 m s$^{-1}$. Find:

**a** the greatest height above the point of projection reached by the pebble

**b** the time taken to reach this height.

**5** A ball is projected upwards from a point which is 4 m above the ground with speed 18 m s$^{-1}$. Find:

**a** the speed of the ball when it is 15 m above its point of projection

**b** the speed with which the ball hits the ground.

**6** A particle $P$ is projected vertically downwards from a point 80 m above the ground with speed 4 m s$^{-1}$. Find:

**a** the speed with which $P$ hits the ground **b** the time $P$ takes to reach the ground.

**7** A particle $P$ is projected vertically upwards from a point $X$. Five seconds later $P$ is moving downwards with speed 10 m s$^{-1}$. Find:

**a** the speed of projection of $P$

**b** the greatest height above $X$ attained by $P$ during its motion.

**8** A ball is thrown vertically upwards with speed 21 m s$^{-1}$. It hits the ground 4.5 s later. Find the height above the ground from which the ball was thrown.

**9** A stone is thrown vertically upward from a point which is 3 m above the ground, with speed 16 m s$^{-1}$. Its motion is modelled as that of a particle moving freely under gravity. Sketch a speed-time graph of the motion of the stone from the time it is projected to the time it hits the ground. Show clearly the time at which the stone is instantaneously stationary, the total time of flight, and the speed of the stone when it hits the ground. **(5 marks)**

**Hint** Speed is the magnitude of velocity. Its value cannot be negative.

**10** A particle is projected vertically upwards with speed 24.5 m s$^{-1}$. Find the total time for which it is 21 m or more above its point of projection.

**11** A particle is projected vertically upwards from a point $O$ with speed $u$ m s$^{-1}$. Two seconds later it is still moving upwards and its speed is $\frac{1}{3}u$ m s$^{-1}$. Find:

**a** the value of $u$ **(3 marks)**

**b** the time from the instant that the particle leaves $O$ to the instant that it returns to $O$. **(4 marks)**

**Problem-solving**

Use $v = u + at$ and substitute $v = \frac{1}{3}u$.

E/P **12** A ball $A$ is thrown vertically downwards with speed $5\,\text{m s}^{-1}$ from the top of a tower block 46 m above the ground. At the same time as $A$ is thrown downwards, another ball $B$ is thrown vertically upwards from the ground with speed $18\,\text{m s}^{-1}$. The balls collide. The motion of the balls is modelled as that of particles moving freely under gravity. Find the distance of the point where $A$ and $B$ collide from the point where $A$ was thrown. **(5 marks)**

E/P **13** A ball is released from rest at a point which is 10 m above a wooden floor. Each time the ball strikes the floor, it rebounds with three-quarters of the speed with which it strikes the floor. Modelling the motion of the ball as that of a particle moving freely under gravity, find the greatest height above the floor reached by the ball

**Problem-solving**

Consider each bounce as a separate motion.

**a** the first time it rebounds from the floor **(3 marks)**

**b** the second time it rebounds from the floor. **(4 marks)**

**Challenge**

1 A particle $P$ is projected vertically upwards from a point $O$ with speed $12\,\text{m s}^{-1}$. One second after $P$ has been projected from $O$, another particle $Q$ is projected vertically upwards from $O$ with speed $20\,\text{m s}^{-1}$. Find: **a** the time between the instant that $P$ is projected from $O$ and the instant when $P$ and $Q$ collide, **b** the distance of the point where $P$ and $Q$ collide from $O$.

2 A stone is dropped from the top of a building and two seconds later another stone is thrown vertically downwards at a speed of $25\,\text{m s}^{-1}$. Both stones reach the ground at the same time. Find the height of the building.